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HEC River Analysis System (HEC-RAS)

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HEC River Analysis System (HEC-RAS)

Gary Brunner[1] and Vernon Bonner[2]

Abstract

The Hydrologic Engineering Center (HEC) is developing next generation software for one-dimensional river hydraulics. The *HEC-RAS River Analysis System* (HEC, 1994) is intended to be the successor to the current steady-flow *HEC-2 Water Surface Profiles* Program (HEC, 1990a) as well as provide unsteady flow, sediment transport, and hydraulic design capabilities. A common data representation of a river network is used by all modeling methods, thus allowing the user to more easily migrate from steady-flow to other one-dimensional flow calculations. The concept also provides a consistent usage of data among the modeling methods. The HEC-RAS program provides a steady-flow model with several significant advances over HEC-2. An overview of the program package and some of the improved hydraulic features are presented. The Version 1.0 steady-flow model is targeted to be released early in 1995, and unsteady-flow capability is planned for the following year.

Introduction

HEC has initiated the development of the Next Generation (NexGen) of hydrologic engineering software (Davis, 1993). While the existing software will continue to be maintained, the NexGen project is an acknowledgement that some HEC software packages have evolved as far as they should. New software is being developed for the engineering desk-top computer. Presently, a new *Hydrologic Modeling System (HEC-HMS)* is under development to be the successor to the *HEC-1 Flood Hydrograph Package* (HEC, 1990b). HEC-HMS is being developed for the Unix Workstation using a Graphical User Interface (GUI) based on OSF/Motif standard. The *HEC-RAS* has been developed for the high-end personal computer operating in a Windows™ environment. Both modeling systems will eventually be implemented on PC and Unix computers. Successor programs are planned for other hydrologic and planning analysis software.

Acknowledgement

This paper is a combination of two, developed and presented by the authors. Co-authors included Mark Jensen, Co-Op Student, who was responsible for the HEC-RAS GUI and graphics, and Steven Piper, Hydraulic Engineer, who developed major portions of the new program code. Model testing, reported herein, was performed by Ken Yokoyama, student intern from UC Davis. Mr. Gary Brunner is team leader for this project.

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HEC-RAS Overview

The HEC-RAS is an integrated package, designed for interactive use in a multi-tasking environment. The system uses a Graphical User Interface (GUI) for file management, data entry and editing, program execution, and output display. The system is designed to provide one-dimensional river modeling using steady-flow, unsteady-flow and sediment-transport computations based on a single geometric representation of the river network. The first release will provide steady-flow, sub-critical, supercritical, and mixed-flow regime profile calculations for a river network.

The program has been developed based on a single definition of the river geometric data for all modeling methods. The five steps for developing a hydraulic model are: 1. Create a project file, 2. Develop the river network and enter geometric data, 3. Define flow and boundary conditions, 4. Perform hydraulic analysis, 5. Review results and produce reports.

A **Project File** is a set of data files associated with a particular river system. Within a project, **Plans** can be developed from combinations of geometric and flow data, plus boundary conditions and run specifications. All input and output data for a plan are linked and assembled by the file manager.

River Networks are defined by drawing, with a mouse, a schematic of the river reaches from upstream to downstream, as shown in the Geometric Data Window in Figure 1. Each **River Reach** is identified by a name. As reaches are connected together, **Junctions** are automatically formed. Junctions are also identified by name. After the network is defined, reach and junction input data can be entered. The data editors can be called by pressing the appropriate buttons on the right of the Geometric Data Window. Or, reach data can be imported from existing HEC-2 data sets.

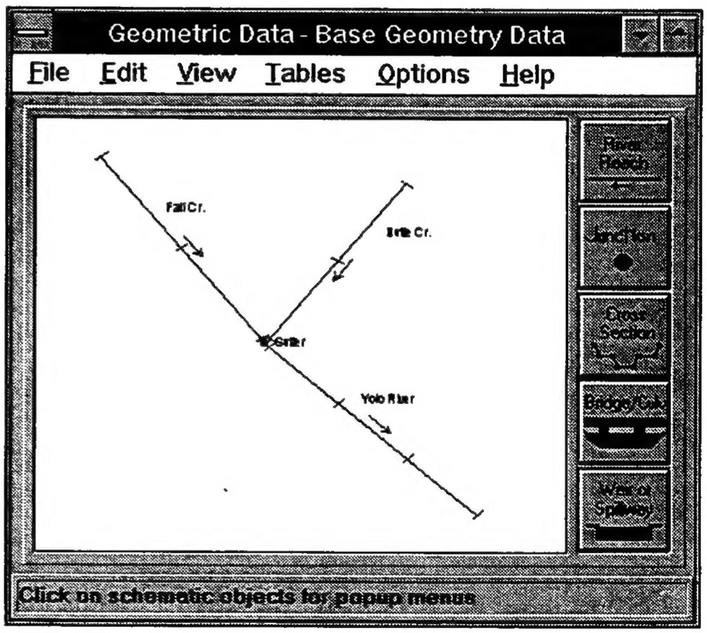

Figure 1. Geometric Data Window.

Junctions are created in the network when reaches combine or divide. The junction is treated as a separate model element; either energy or momentum-based calculations can be performed at the junctions. Energy calculations are based on a reach length between the reaches, the momentum calculation also requires the angle of approach for the reach.

Cross sections are located by the reach name and river station. Pressing the cross-section icon provides the data entry editor. Data are defined by station-elevation

coordinates, up to 500 coordinates are allowed. There is no maximum number of cross sections. The section data are stored in a downstream order based on their river-station number. Cross sections can be easily added or modified in any order. Cut, paste, and copy features are provided, along with separate expansion or contraction of the cross-section elements of overbanks and channel. Cross section interpolation will be provided using cross section coordinates or hydraulic tables.

Steady-flow data are defined for the reach at any cross-section location. Multiple-profile calculations are supported. The boundary conditions are defined at downstream, and/or upstream ends of reaches depending on flow regime. Internal boundary conditions are defined by the junctions. The HEC-2 options for starting profile calculations are all supported.

Profile calculations are performed using the standard-step procedure. Overbank conveyance is computed incrementally at coordinate points (HEC-2 style) or at breaks in roughness (HEC-RAS default). Subcritical, supercritical, and mixed-flow profile calculations can be performed. The critical-depth routine searches the entire range of depths and locates multiple minima. The transition between supercritical and subcritical flow is determine based on momentum calculations. Detailed hydraulic jump location and losses are not computed; however, the jump location is defined between two cross sections.

Tabular output is available using pre-defined and user-defined tables. Cross-section tables provide detailed hydraulic information at a single location, for a profile. Up and down arrow buttons allow the user to page through the output or select specific cross sections. Profile tables provide summary information for all cross sections and profiles. Several pre-defined summary tables are available for the cross section, bridge, and culvert computations. User-defined tables can be developed from a menu of 120 output variables. Selected variables can be stored and recalled like pre-defined tables.

Graphical displays are available for cross sections, profiles, and rating curves. The geometric data can be displayed from the **View** option, provided in most of the data-input editors. Computed results are available as cross section, profiles and rating curves from the **View** menu on the HEC-RAS Main Window. User control is provided for variables to plot, line color, width and type, plus axis labels and scales. The user can also zoom-in on selected portions of the display, and zoom-out to the original size. All graphics are in vector form using calls to the Window's™ Graphics Device Interface. Graphics can be sent to output devices through the Window's™ print manager, or they can be written to a meta file or sent to the Window's™ clip board.

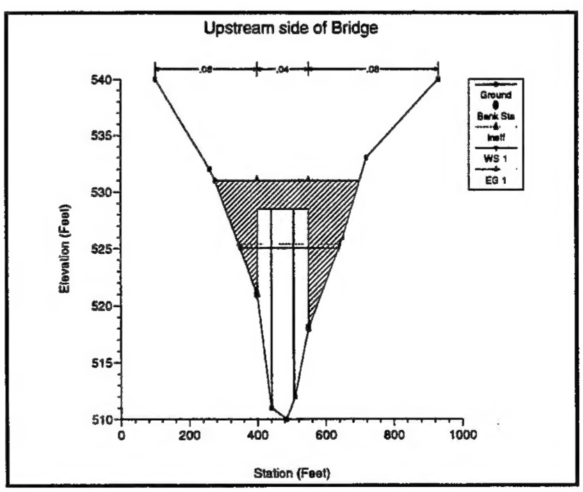

Figure 2. Cross Section Bridge Plot.

Documentation includes a User's Manual (HEC, 1994), plus a Technical, Engineering and Application Reference documents are planned. The user's manual provides the basics for loading and using the software. The reference manuals are intended to provide the hydraulic equations, engineering assumptions, and technical details on menu options, error messages, and basic trouble-shooting.

Alternative Channel Subdivision for Conveyance Calculations

Both HEC-RAS and HEC-2 utilize the Standard Step method for balancing the energy equation to compute a water surface at a cross section. A key element in the solution of the energy equation is the calculation of conveyance. The conveyance is used to determine friction losses between cross sections, the flow distribution at a cross section, and the velocity weighing coefficient alpha. The approach used in HEC-2 is to calculate conveyance between every coordinate point in the cross section overbanks (Figure 3). The conveyance is then summed to get the total left overbank and right overbank values. HEC-2 does not subdivide the main channel for conveyance calculations. The HEC-RAS program supports this method for calculating conveyance, but the default method is to make conveyance calculations only at n-value break points (Figure 4).

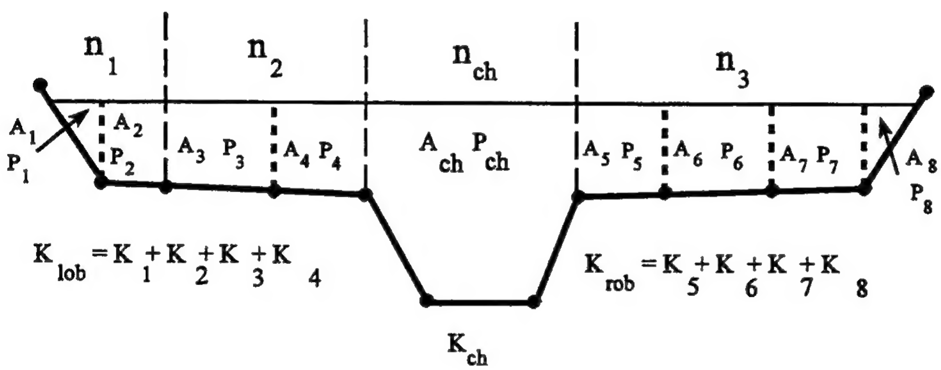

Figure 3. HEC-2 Conveyance Subdivision

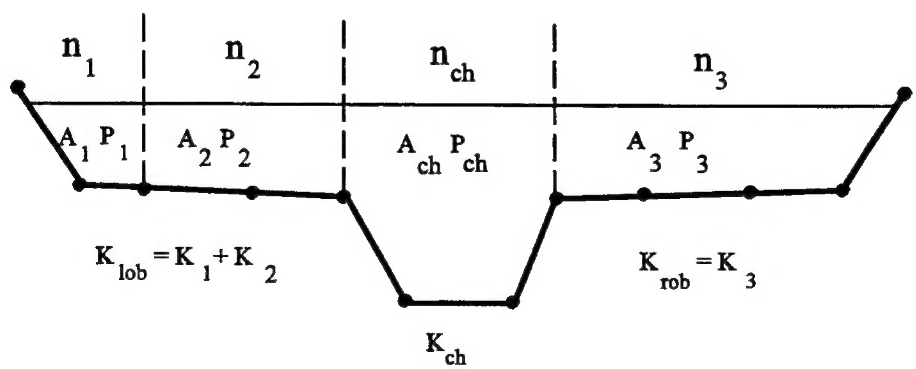

Figure 4. HEC-RAS Conveyance Subdivision

Testing Using HEC-2 Approach. Comparisons of HEC-RAS results with those from HEC-2 were performed using 97 data sets from the HEC profile accuracy study (HEC, 1986). Water surface profiles were computed for 10% and 1% chance floods using HEC-2 and HEC-RAS, both programs using the HEC-2 approach for computing overbank conveyance. Table 1 shows the percentage, of approximately 2000 cross sections, within ∓6 mm (∓.02 feet). For the 10% chance flood, 53 cross sections had difference greater than ∓6 mm. For those sections, 62.2% were caused by differences in computation of critical depth and 34% resulted from propagation of the difference upstream. For the 1% chance flood, 88 sections had elevation differences over ∓6 mm, of which 60.2% resulted from critical depth and 36.4% from the upstream propagation. HEC-RAS uses 3 mm (0.01 feet) for the critical depth error criterion, while HEC-2 uses 1% of the flow.

Table 1. Computed Water Surface Elevation Difference (HEC-RAS - HEC-2)

Difference (mm)	-6	-3	0.0	3	6	Total
10% Chance Flood	0.8%	11.2%	73.1%	11.2%	0.6%	96.9%
1% Chance Flood	2.0%	11.6%	70.1%	10.8%	1.3%	95.8%

Testing Using RAS and HEC-2 Approach. The two methods for computing conveyance will produce different answers whenever portions of the overbanks have ground sections with significant vertical slopes. In general, the HEC-RAS default approach will provide a lower total conveyance for the same elevation and, therefore, a higher computed water surface elevation. In order to test the significance of the two ways of computing conveyance, comparisons were performed using the same 97 data sets. Water surface profiles were computed for the 1% chance event using the two methods for computing conveyance in HEC-RAS. The results confirmed that the HEC-RAS default approach will generally produce a higher computed water surface elevation. Out of the 2048 cross section locations, 47.5% had computed water surface elevations within 30.5 mm (0.10 ft.), 71% within 61 mm (0.20 ft.), 94.4% within 122 mm (0.4 ft.), 99.4% within 305 mm (1.0 ft.), and one cross section had a difference of 0.84 m (2.75 ft.). Because the differences tend to be in the same direction, some effects can be attributed to propagation.

The results from these comparisons do not show which method is more accurate, they only show differences. In general, it is felt that the HEC-RAS default method is more commensurate with the Manning equation and the concept of separate flow elements. Further research, with observed water surface profiles, will be needed to make any conclusions about the accuracy of the two methods.

Mixed Flow Regime Calculations The HEC-RAS software has the ability to perform subcritical, supercritical, or mixed flow regime calculations (without requiring the user to re-order the cross section data). Mixed flow regime calculations are accomplished in two stages. First, a subcritical water surface profile is computed starting from a known downstream boundary condition. During the subcritical calculations, all locations where the program defaults to critical depth are flagged for further analysis. The next step is to perform supercritical profile calculations. The program starts at the upstream boundary and begins checking for locations that defaulted to critical depth in the subcritical run.

When a critical depth is located, the program uses it as a boundary condition to begin a supercritical profile calculation. The program calculates a supercritical profile in the downstream direction until it reaches a cross section that has both a subcritical and a supercritical answer. When this occurs, the program calculates the momentum of both computed water surface elevations. Whichever answer has the greater momentum is considered to be the correct solution. If the supercritical answer has a greater momentum, the program continues making supercritical calculations in the downstream direction and comparing the momentum of the two solutions. When the program reaches a cross section whose subcritical answer has a greater momentum, the program assumes that a hydraulic jump occurred between that section and the previous cross section. The program then goes to the next downstream location that has a critical depth answer and continues the process. An example mixed flow profile from HEC-RAS is shown in Figure 5, adapted from a problem in Chow's "Open Channel Hydraulics" (Chow, 1959).

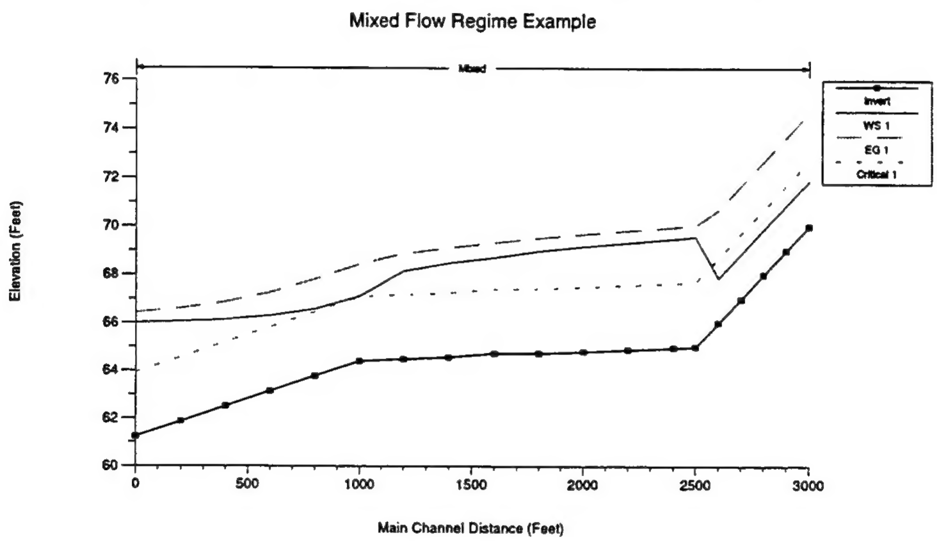

Figure 5. Example Mixed Flow Profile From HEC-RAS

Modeling Full Stream Networks and Junctions

The HEC-RAS system has the ability to model dendritic river systems, as well as a full network of streams. The program can handle an unlimited number of river reaches. Junctions (locations where reaches either combine or split) are limited to five reaches either combining or splitting. The water surface profile through a junction can be modeled in two different ways. The default method is to use the energy equation. An energy balance is performed across the junction on a reach by reach basis. The user has the option of selecting an alternative method that utilizes the momentum equation. The momentum equation allows the user to enter an angle for each reach that is not parallel to the normal direction of flow. The program then performs a momentum balance across the junction to obtain the water surface profiles.

New Bridge and Culvert Routines

The **Bridge Routines** in HEC-RAS allow the modeler to analyze a bridge by several different methods without changing the bridge geometry. The model utilizes four user defined cross sections in the computations of energy losses due to the structure. Cross sections are formulated inside the bridge on an as need basis by combining the bridge geometry with the two cross sections that bound the structure.

For **Low Flow Computations** the program first uses the momentum equation to define the class of flow. For Class A low flow (completely subcritical), the modeler can select any or all of the following four methods: standard step energy; momentum; Yarnell equation; or USGS Contracted Opening method. If more than one method is selected, the user must choose a single method as the final solution, or tell the program to select the method that produces the highest energy loss through the structure. For Class B low flow (passes through critical depth) the program uses the momentum equation. Class C low flow (completely supercritical) can be modeled with either the standard step energy method or the momentum equation. The program does not require the user to enter a trapezoidal approximation for the bridge opening. Also, for the momentum method, the user can instruct the program to incorporate weight and/or friction components in addition to the pier impact losses.

Pressure Flow occurs when the flow comes into contact with the low cord of the bridge. The program begins checking for the possibility of pressure flow when the energy grade line goes above the maximum low chord. The user has the option of telling the program to use the water surface instead of energy. The program will handle two cases of pressure flow. The first is when only the upstream side of the bridge is in contact with the flow (sluice gate). In the second case, both the upstream and downstream side of the bridge are in contact with the flow (orifice equation).

Weir Flow occurs when water flows over the bridge and/or roadway. Weir flow is calculated using a standard weir equation. For high tailwater conditions, the amount of weir flow is reduced to account for the effects of submergence. If the weir becomes highly submerged, the program will switch to calculating energy losses by the standard step energy method. The criteria for when the program switches to energy based calculations is user controllable. When combinations of low flow or pressure flow occur with weir flow, an iterative procedure is used to determine the amount of each type of flow.

The **Culvert** hydraulic computations in HEC-RAS are similar to the bridge routines, in that the cross section layout, the use of ineffective areas, the selection of contraction and expansion coefficients. and other aspects are the same. The culvert routines have the ability to model the following shapes: box; circular; arch; pipe arch; and elliptical. The program uses the Federal Highway Administrations (FHWA, 1985) standard culvert equations to model inlet control. Outlet control is analyzed by either standard step backwater calculations or full flow friction losses. Entrance and exit losses are incorporated in both options.

Program Testing

Initial testing has consisted of comparing results to the current HEC-2 program. Additional testing is now underway using all the observed data we can locate. The bridge routines are being extensively tested using 21 USGS data sets from the Bay St. Louis

After all the testing has been completed, and final corrections and additions have been made, HEC will release the first official version.

Distribution

After extensive internal and volunteer testing have been completed, and the necessary program corrections and additions are finished, HEC will release the Version 1 steady-flow model for general use. Work will continue to add additional features to the steady-flow capability and to add unsteady flow modeling. Major program releases are expected approximately annually during the development of the program package. The addition of hydraulic design, scour, and sediment transport capability is planned for future development.

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FIELD	GROUP	SUB-GROUP	Water surface profiles, HEC-RAS computer program, microcomuter

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The Hydrologic Engineering Center (HEC) is developing next generation software for one-dimensional river hydraulics. The HEC-RAS River Analysis System is intended to be the successor to the current steady-flow HEC-2 Water Surface Profiles Program as well as provide unsteady flow, sediment transport, and hydraulic design capabilities in the future. A common data representation of a river network is used by all modeling methods, thus allowing the user to more easily migrate from steady-flow model with several significant advances over HEC-2. An overview of the Version 1 program package and some of the improved hydraulic features are presented.

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